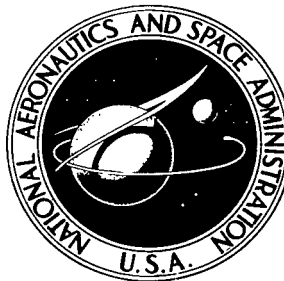


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THERMAL AND RADIATIVE PROPERTY MEASUREMENT OF THERMAL-CONTROL COATINGS BY CYCLIC RADIATION

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THERMAL AND RADIATIVE PROPERTY MEASUREMENT OF THERMAL-CONTROL COATINGS BY CYCLIC RADIATION

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SUMMARY

A technique is described and developed whereby the cyclic radiation method of determining thermal radiative properties is used to determine simultaneously the specific heat, absorptance, and emittance of thermal-control coatings. Data are presented for four white coatings (3M white, S-13G, Z-93, and Cat-a-lac white) and two black coatings (3M black and Cat-a-lac black) over a temperature range from approximately 150 to 300 K. An additional application of the cyclic radiation technique is illustrated by determining the specific heat of a 302 stainless steel sample by coating the sample with 3M black coating and using previously measured properties of the coating as a reference.

INTRODUCTION

The thermal radiative properties of paints and coatings are of continuing interest because of their use for passive thermal control of spacecraft. The properties of paints and coatings (especially white coatings) tend to degrade with exposure to the space environment. Ground determinations of thermal radiative properties are of limited value because of the difficulty in simulating the space environment and determining the actual rate of degradation of these coatings. It is necessary, therefore, that space experiments continue to be considered and undertaken if the degradation effect of the space environment on coatings is to be established.

The space experiments which have been used to determine the properties of coatings are (and probably will continue to be) of the calorimetric type. The reason for this is that such experiments require only that the temperature response of suitable samples to changes in the incident radiant heat load need be measured. A requirement for accuracy of calorimetric methods is that the thermal mass of the coating and substrate material

be known over a wide range of temperatures. Only meager specific-heat data for paints and coatings are available.

This report describes a procedure by which the cyclic radiation method of reference 1 can be modified and used to determine the specific heat of coatings and other materials so that calorimetric methods can be used more confidently for space experiments. The method was applied to determine simultaneously the thermal radiative properties and the specific heat of six thermal-control coatings (four white and two black coatings). The method was further used to determine the specific heat of a metal alloy (stainless steel 302) by using the measured properties of one of the black coatings as a reference.

THEORETICAL BACKGROUND

The cyclic radiant intensity method is presented in detail in reference 2. Briefly, the application of the method requires a thin, flat and consequently isothermal sample that is carefully suspended in an ultra-high-vacuum cold-wall environment. A collimated beam of radiant energy is imposed normal to one surface of the sample. After the sample has achieved thermal equilibrium, the radiant intensity is varied sinusoidally about a mean intensity level I_0 with a frequency ω and an amplitude kI_0 . (Symbols are defined in the appendix.) For small radiant intensity variations, the temperature of the sample at cyclic equilibrium lags the incident radiation by a phase angle φ and is also sinusoidal about the mean equilibrium temperature T_m with amplitude A . The temperature amplitude and phase angle are given by (see ref. 2)

$$A = \frac{\alpha_s k I_0 \sin \varphi}{\omega w c_p} \quad (1)$$

and

$$\varphi = \tan^{-1} \frac{\omega w c_p}{4\sigma(\epsilon_T + \epsilon_B)T_m^3} \quad (2)$$

When the mean sample temperature, phase angle, and temperature amplitude are measured, the absorptance of the surface to the incident radiation is

$$\alpha_s = \left(\frac{A \omega w c_p}{k I_0 \sin \varphi} \right)_s \quad (3)$$

and the average of the hemispherical emittance of the top and bottom surfaces is given by

$$\epsilon_s = \frac{\epsilon_T + \epsilon_B}{2} = \left(\frac{\omega w c_p}{8\sigma T_m^3 \tan \varphi} \right)_s \quad (4)$$

A subscript s has been introduced into equations (3) and (4) to designate thermal radiative property data which can be obtained for a simple metallic material of known weight per unit area w and specific heat c_p whose emittances on the top and bottom surfaces are equal.

The thermal radiative property data and specific heat of a coating can now be determined in the following manner. After the radiative properties of the metal substrate have been determined by equations (3) and (4), the coating of interest is applied to the bottom surface of the substrate and the coated sample is again exposed to the cyclic radiation. The absorptance of the top surface of the sample (which has not been altered) is given by

$$\alpha_s = \left(\frac{A\omega}{kI_o \sin \varphi} \right)_{cb} \left[(wc_p)_s + (wc_p)_c \right] \quad (5)$$

and the sum of the emittances of the top and bottom surfaces is given by

$$\epsilon_c + \epsilon_s = \left(\frac{\omega}{4\sigma T_m^3 \tan \varphi} \right)_{cb} \left[(wc_p)_s + (wc_p)_c \right] \quad (6)$$

The subscripts c and cb refer to the sample with the coating and the coating on the bottom, respectively. The coating specific heat and hemispherical emittance can be determined in terms of the substrate absorptance and emittance from equations (3) to (6) as

$$(c_p)_c = \frac{\alpha_s}{w_c} \left(\frac{kI_o \sin \varphi}{A\omega} \right)_{cb} - \frac{(wc_p)_s}{w_c} \quad (7)$$

and

$$\epsilon_c = \alpha_s \left(\frac{kI_o \cos \varphi}{4\sigma AT_m^3} \right)_{cb} - \epsilon_s \quad (8)$$

If the coated sample is now turned over so that the coating is exposed to the cyclic radiation, the coating absorptance and the sum of the emittances of the sample surfaces are given by

$$\alpha_c = \left(\frac{A\omega}{kI_o \sin \varphi} \right)_{ct} \left[(wc_p)_s + (wc_p)_c \right] \quad (9)$$

and

$$\epsilon_c + \epsilon_s = \left(\frac{\omega}{4\sigma T_m^3 \tan \varphi} \right)_{ct} \left[(wc_p)_s + (wc_p)_c \right] \quad (10)$$

The subscript *ct* is applied to indicate data obtained for the sample with the coating on top or facing the incident radiation. The coating absorptance can be determined from equation (9) in terms of the previously determined coating specific heat or in terms of the coating emittance by substituting equation (10) into equation (9)

$$\alpha_c = \left(\frac{4\sigma AT_m^3}{kI_o \cos \varphi} \right)_{ct} (\epsilon_c + \epsilon_s) \quad (11)$$

Either equation (9) or (11) can be used to determine the coating absorptance. We have generally tended to use equation (11) for coatings because the uncertainty in the determination for coating emittance ($\epsilon_c \approx 1.0$) is generally less than the uncertainty in the coating specific heat.

UNCERTAINTY ANALYSIS

An uncertainty analysis (ref. 3) is useful for estimating the accuracy with which the radiative properties can be determined. The analysis is also useful for establishing the

experimental parameters of importance so that they can be selected to minimize the uncertainties inherent in the method. The uncertainty in the absorptance and emittance of the substrate material (as given by eqs. (3) and (4)) is

$$\frac{\delta(\alpha_s)}{\alpha_s} = \left\{ \left[\frac{\delta(w)}{w} \right]^2 + \left[\frac{\delta(c_p)}{c_p} \right]^2 + \left[\frac{\delta(\omega)}{\omega} \right]^2 + \left[\frac{\delta(kI_o)}{kI_o} \right]^2 + \left[\frac{\delta(A)}{A} \right]^2 + \left[\frac{\delta(\sin \varphi)}{\sin \varphi} \right]^2 \right\}_s^{1/2} \quad (12)$$

and

$$\frac{\delta(\epsilon_s)}{\epsilon_s} = \left\{ \left[\frac{\delta(w)}{w} \right]^2 + \left[\frac{\delta(c_p)}{c_p} \right]^2 + \left[\frac{\delta(\omega)}{\omega} \right]^2 + \left[\frac{3\delta(T_m)}{T_m} \right]^2 + \left[\frac{\delta(\tan \varphi)}{\tan \varphi} \right]^2 \right\}_s^{1/2} \quad (13)$$

If a conservative estimate of the uncertainty for all of the measured experimental parameters of 0.02 (2 percent) is used, the uncertainty of the absorptance determination is 0.05 and the emittance uncertainty is 0.07.

The uncertainty of the coating specific heat and emittance based upon equations (7) and (8) is

$$\begin{aligned} \frac{\delta(c_p)_c}{(c_p)_c} = & \left(\left[1 + \frac{(wc_p)_s}{wc_p_c} \right]^2 \left\{ \left[\frac{\delta(\alpha_s)}{\alpha_s} \right]^2 + \left[\frac{\delta(\omega)}{\omega} \right]^2 + \left[\frac{\delta(\sin \varphi)}{\sin \varphi} \right]^2 + \left[\frac{\delta(A)}{A} \right]^2 + \left[\frac{\delta(w_c)}{w_c} \right]^2 \right\} \right. \\ & \left. + \left[\frac{(wc_p)_s}{(wc_p)_c} \right]^2 \left\{ \left[\frac{\delta(w_c)}{w_c} \right]^2 + \left[\frac{\delta(w_s)}{w_s} \right]^2 + \left[\frac{\delta(c_p)_s}{(c_p)_s} \right]^2 \right\} \right)^{1/2} \end{aligned} \quad (14)$$

and

$$\begin{aligned} \frac{\delta(\epsilon_c)}{\epsilon_c} = & \left(\left(1 + \frac{\epsilon_s}{\epsilon_c} \right)^2 \left\{ \left[\frac{\delta(\alpha_s)}{\alpha_s} \right]^2 + \left[\frac{\delta(kI_o)}{kI_o} \right]^2 + \left[\frac{\delta(A)}{A} \right]^2 + \left[\frac{3\delta(T_m)}{T_m} \right]^2 + \left[\frac{\delta(\cos \varphi)}{\cos \varphi} \right]^2 \right\} \right. \\ & \left. + \left(\frac{\epsilon_s}{\epsilon_c} \right)^2 \left[\frac{\delta(\epsilon_s)}{\epsilon_s} \right]^2 \right)^{1/2} \end{aligned} \quad (15)$$

The two terms which govern the accuracy with which the coating specific heat can be determined are the ratio of the substrate to coating thermal mass $(wc_p)_s/(wc_p)_c$ and the uncertainty in the substrate absorptance determination. The thermal mass of the substrate should be as small as possible. For example, for a thermal mass ratio of 1.0, an uncertainty in the substrate absorptance of 0.05, and an uncertainty of 0.02 for all other experimental parameters, the maximum uncertainty in the coating specific heat is 0.14. It should be observed that as the thermal mass ratio decreases the coating specific-heat uncertainty also decreases and that the minimum uncertainty obtainable is 0.07 for negligible substrate thermal mass.

The terms of primary importance for the determination of coating emittance are the substrate to coating emittance ratio and the uncertainties in the substrate absorptance and emittance. The emittance of the substrate should be as small as possible. For an emittance ratio of 0.1, an uncertainty for substrate absorptance and emittance of 0.05 and 0.07, respectively, and an uncertainty of 0.02 for all other parameters, the uncertainty in the coating emittance is 0.09. If the substrate and coating emittance values are approximately the same, the uncertainty is 0.17.

The uncertainty in the coating absorptance as determined by equation (11) is

$$\frac{\delta(\alpha_c)}{\alpha_c} = \left\{ \left[\frac{\delta(A)}{A} \right]^2 + \left[\frac{\delta(kI_o)}{kI_o} \right]^2 + \left[\frac{3\delta(T_m)}{T_m} \right]^2 + \left[\frac{\delta(\cos \varphi)}{\cos \varphi} \right]^2 + \left[\frac{\epsilon_s}{\epsilon_s + \epsilon_c} \frac{\delta(\epsilon_s)}{\epsilon_s} + \frac{\epsilon_c}{\epsilon_s + \epsilon_c} \frac{\delta(\epsilon_c)}{\epsilon_c} \right]^2 \right\}^{1/2} \quad (16)$$

The important term is the uncertainty in the coating emittance. For a coating emittance uncertainty of 0.09, low substrate emittance ($\epsilon_s < 0.05$), and an uncertainty of 0.02 for all other terms, the maximum absorptance uncertainty is 0.12. An independent determination of the coating specific heat can be obtained from equation (10) for the sample with the coating on the top surface as

$$(c_p)_c = \left(\frac{4\sigma T_m^3 \tan \varphi}{\omega w_c} \right)_{ct} (\epsilon_s + \epsilon_c) - \frac{(wc_p)_s}{w_c} \quad (17)$$

The uncertainty in the coating specific heat as determined from equation (17) as

$$\begin{aligned} \frac{\delta (c_p)_c}{(c_p)_c} = & \left(\left[1 + \frac{(wc_p)_s}{(wc_p)_c} \right]^2 \left\{ \left[\frac{3\delta(T_m)}{T_m} \right]^2 + \left[\frac{\delta(\tan \varphi)}{\tan \varphi} \right]^2 + \left[\frac{\delta(\omega)}{\omega} \right]^2 + \left[\frac{\delta(w_c)}{w_c} \right]^2 \right. \right. \\ & + \left. \left[\frac{\epsilon_s}{\epsilon_s + \epsilon_c} \frac{\delta(\epsilon_s)}{\epsilon_s} \right]^2 + \left. \left[\frac{\epsilon_c}{\epsilon_s + \epsilon_c} \frac{\delta(\epsilon_c)}{\epsilon_c} \right]^2 \right\} + \left[\frac{(wc_p)_s}{(wc_p)_c} \right]^2 \left\{ \left[\frac{\delta(w_s)}{w_s} \right]^2 \right. \right. \\ & \left. \left. + \left[\frac{\delta(w_c)}{w_c} \right]^2 + \left. \left[\frac{\delta(c_p)_s}{(c_p)_s} \right]^2 \right\} \right)^{1/2} \end{aligned} \quad (18)$$

For a thermal mass ratio of 1.0, small substrate emittance, an uncertainty of 0.09 in coating emittance, and an uncertainty 0.02 in all other experimental parameters, the uncertainty in the coating specific heat is 0.23. Thus, the uncertainty of determining specific heat from equation (17) is greater than that from equation (7).

PROCEDURE

Experimental data were obtained in the ultra-high-vacuum, liquid-helium-cooled facility described in reference 2. A sketch of the experimental arrangement used to obtain coating data is shown in figure 1. The sample arrangement of figure 1 was used for convenience so that all of the data necessary for determining the specific heat, absorptance, and emittance of the coating could be obtained simultaneously from a series of data runs. Such an arrangement did not require removing the sample from the vacuum facility and thus disturbing the sample instrumentation and mounting. The carbon arc lamp discussed in reference 4 was used as the radiant source. The average radiant intensity levels were varied from 0.05 to 1.0 solar constants in order to obtain data over a range of temperatures.

Data were obtained on the six different coatings shown in table I. The sample specimens were approximately 1.5 centimeters wide by 3.0 centimeters long. The substrate material for all coatings was 0.00254-centimeter (0.001-in.) molybdenum. The samples were prepared as carefully and as consistently as possible to ensure that the sample surfaces were not contaminated during the coating, instrumentation, or mounting operations. Each sample was supported in the test plane by four 0.00254-centimeter (0.001-in.) wires which were spot-welded to the four corners. Two of the support

wires formed a Chromel-constantan thermocouple which measured the sample temperature response.

The three substrate sections were cut to size from a common section of a large sheet of rolled molybdenum to ensure that the surface characteristics were as nearly identical as possible. The surfaces were cleaned and weighed to determine the substrate weight per unit area. Two of the samples were then coated and vacuum-baked overnight. The samples were again weighed to determine the coating weight per unit area. Support and thermocouples wires were then attached to the samples and a final alcohol wash was given to all uncoated surfaces. The samples were again given a mild, overnight vacuum bake to remove any absorbed water and then installed in the vacuum tank and kept at vacuum conditions until the necessary data were obtained. Once the samples were removed from the vacuum facility, no additional calorimetric data were taken.

RESULTS AND DISCUSSION

The radiative property data obtained for the molybdenum substrate sample are shown in figures 2 and 3. The ϵ_s/c_p and α_s/c_p data are presented and represent the experimentally measured values for six different substrate samples used during six independent data runs. The scatter is within ± 3 percent for the ϵ_s/c_p data and within ± 8 percent for α_s/c_p . The hemispherical emittance and solar absorptance of the substrate using the specific-heat data of reference 5 and the faired curves from figures 2 and 3 are shown in figure 4.

The molybdenum emittance increases almost linearly with increasing temperature. The solar absorptance is approximately constant at a value of 0.34 over the temperature range from 300 to 500 K. Below 300 K and above 500 K, the solar absorptance tends to decrease slightly. However, the solar absorptance can be considered constant within the estimated uncertainty of the data.

The specific heat, emittance, and solar absorptance for each of the six coatings are shown in figures 5 to 10. In addition to the cyclic data, a room-temperature solar-absorptance value obtained from spectral reflectance integrating sphere data (ref. 6) is also shown for comparison purposes.

The coating specific heats obtained from both equations (7) and (17) (using the faired curve for the coating emittance) are shown. The comparison between the two sets of data is generally quite good despite the fact that the uncertainty of equation (17) is high. The specific heats of all the coatings follow the generally accepted trend and increase with increasing temperature.

For comparison purposes, the specific heats for 3M black velvet paint presented in reference 7 are shown. The data of reference 7 are approximately 40 percent higher

than the data obtained here. The reasons for this difference cannot be identified at this time.

The emittance of the six different coatings indicate the expected trend of increasing emittance with increasing temperature.

The solar absorptances of the white coatings tend to remain relatively constant, while the absorptances of the black coatings tend to increase almost linearly with temperature over the temperature range covered.

In order to obtain accurate data for coatings from the cyclic method, or any calorimetric method, careful consideration must be given to the substrate selection and great care must be exercised in the sample preparation. The molybdenum substrate used herein satisfied most of the requirements of the cyclic method and in addition could be easily handled, cleaned, coated, and instrumented. Small substrate thermal mass and rapid response rates were achieved with 0.0025-centimeter- (0.001-in. -) thick foil. The lower the ratio of the substrate to coating thermal mass, the more accurately the specific heat can be determined. The ratio of substrate to coating thermal mass ranged from 0.23 for the S-13G white coating to 1.5 for the Cat-a-lac black coating. The lower the substrate emittance, the lower the uncertainty for the coating emittance. The 0.05 emittance of molybdenum at 300 K helps minimize the uncertainty in the coating emittance. The most serious disadvantage of the molybdenum substrate was the high α_s/ϵ_s of the material and the corresponding high temperatures for a given radiant intensity as compared to the composite sample with the coating facing the incident radiation. The coated substrate samples had an α_s/ϵ_c of about 0.4 for the coatings on the bottom and 0.2 for the samples with the white coatings on the top. As a result, the temperature range covered by the coated samples for the radiant intensity range covered (0.05 to 1.0 solar constants) frequently did not overlap the range covered by the reference sample. For example, the temperature range of the molybdenum substrate alone was 300 to 500 K, while the temperature range was 200 to 300 K for the substrate with the S-13G coating on the bottom and 150 to 270 K with the S-13G coating on the top. The problem, of course, was that substrate absorptance and emittance data were not always available at the coated sample temperatures, and it was necessary to extrapolate the substrate property data to lower temperatures. The most serious consequence of the extrapolated data is the resulting uncertainty in the substrate absorptance and the corresponding increase in the uncertainty of the coating properties. A more desirable substrate material would not only have low thermal mass and emittance but would also have an α_s/ϵ_s that matches more closely the α_s/ϵ_c of the coated sample. An alternative would be a radiant source which could be varied over a wider intensity range. Either approach would ensure that the properties of the substrate were known over the coated-sample temperature range.

The only coating which indicated a deterioration or contamination problem was Z-93. Despite careful preparations and handling, a slight discoloration was noted along

the edge of the Z-93 coatings before the samples were mounted in the ultra-high-vacuum facility. Upon inspection after the tests were completed, the discoloration was noted to have spread to both the coated and substrate surfaces. The affected area was, however, quite small and was considered of minor importance. Inspection of the samples a number of weeks after the conclusion of the investigation indicated that the discoloration was continuing to spread to a degree that the samples at this time were unacceptable for testing. The results (particularly an absorptance of 0.11) for the Z-93 coating are lower than the generally quoted value of 0.16 and may be due to the discoloration which occurred.

The experimental approach of using three samples so that all the necessary data can be determined simultaneously introduces possible sources of errors which must be recognized. It is necessary to assume that all substrate surfaces have identical absorptance and emittance values and that the two coated surfaces are also identical. The handling and preparation of the samples were done as carefully as possible; however, no measurements were made to verify that the surfaces were identical. The values of α_s/c_p and ϵ_s/c_p in figures 2 and 3 for the substrate are somewhat reassuring in that the molybdenum surface properties were consistent. The relatively large scatter in the absorptance data of ± 10 percent may indicate, however, that some variations in surface properties did exist. If such variations do exist among the substrates used for the different coatings, differences could also be expected among the different substrate surfaces used for the same coating. A more desirable experiment would have been to obtain data on the substrate first, remove the sample from the vacuum facility, carefully apply the coating, and obtain the remaining data with the coating on the bottom and then with the coating on top. In this manner the substrate and coating data would have been for common surfaces provided the surfaces were not contaminated during the sample changes.

The results of another application of the cyclic technique for determining property data are given in figure 11. The specific heat of a 2.54-centimeter- (1-in. -) diameter 320 stainless steel sample was determined by painting both the top and bottom surfaces of the sample with 3M black paint. From equations (3) and (4) the specific heat of the substrate was related to the specific heat, absorptance, and emittance of the 3M black coating. Using the 3M black data from figure 9, two independent determinations of the substrate specific heat were made in terms of the coating absorptance and emittance from equations (5) and (6). The two sets of data are shown in figure 11 along with the calculated specific heat of an 18-8 stainless steel from reference 8. The comparison at room temperature is within 2 percent. At lower temperatures the comparison is not as good with a difference of 20 percent at 200 K.

CONCLUDING REMARKS

The cyclic radiation method of determining surface radiative properties can be modified and adapted for use to determine the specific heat and radiative properties of thermal-control coatings. Careful consideration must be given to substrate selection, coating application, and experimental procedure in order to obtain accurate data. With good experimental technique the uncertainty in the specific heat, absorptance, and emittance of the coating can be limited to less than 10 percent. The problem of uncertainty is common to all calorimetric methods because the coating must be applied to a substrate and the coating properties inferred from the temperature response of the composite sample and the radiative properties of the substrate. This degree of uncertainty is not desirable but is acceptable until improved methods are available.

The primary advantage of the technique developed herein is that the specific heat of a coating can be determined, and the accuracy of radiative property data obtained from calorimetric space experiments can thereby be improved.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, January 27, 1971,
124-09.

APPENDIX - SYMBOLS

A	amplitude of temperature variation, K
c_p	specific heat, J/(g/K)
I_o	mean radiant intensity, J/(sec/cm ²)
kI_o	amplitude of intensity variation, J/(sec/cm ²)
T_m	mean sample temperature, K
w	weight per unit area, g/cm ²
α	absorptance of surface
ϵ	emittance of surface
ϵ_s	average emittance of substrate top and bottom surfaces
σ	Stefan-Boltzmann constant, J/(sec)(cm ²)(K ⁴)
ϕ	phase angle between sinusoidally varying radiant intensity and sample temperature, rad
ω	frequency of sinusoidal intensity variation, rad/sec

Subscripts:

B	bottom surface of sample
c	coating
cb	coating on bottom surface of sample
ct	coating on top surface of sample
s	substrate sample
T	top surface of sample

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TABLE I. - DESCRIPTION OF SAMPLES AND COATINGS APPLIED TO 0.0025-CENTIMETER-THICK MOLYBDENUM SUBSTRATE

Run	Coating identification	Coating description	Sample painted on bottom				Sample painted on top			
			Total sample weight, g/cm ²	Substrate weight, g/cm ²	Coating weight, g/cm ²	Coating thickness, mm	Total sample weight, g/cm ²	Substrate weight, g/cm ²	Coating weight, g/cm ²	Coating thickness, mm
1	3M white	White velvet coating, air dry enamel, Minnesota Mining and Mfg. Co.	0.0458	0.0301	0.0157	0.15	0.0469	0.0301	0.0168	0.15
2	Cat-a-lac white	Titanium dioxide pigment in epoxy resin, Finch Paint and Chemical Co.	.0447	.0309	.0138	.09	.0432	.0309	.0123	.09
3	S-13G (white)	Potassium-silicate treated zinc oxide in dimethylsilicone	.0668	.0301	.0367	.20	.0650	.0301	.0349	.20
4	Z-93 (white)	Zinc oxide pigment in potassium silicate	.0517	.0302	.0215	.20	.0524	.0302	.0222	.20
5	3M black	Black velvet coating, air dry enamel, Minnesota Mining and Mfg. Co.	.0456	.0303	.0153	.15	.0441	.0303	.0138	.15
6	Cat-a-lac black	Carbon black pigment in epoxy resin, Finch Paint and Chemical Co.	.0377	.0303	.0074	.075	.0369	.0303	.0066	.075

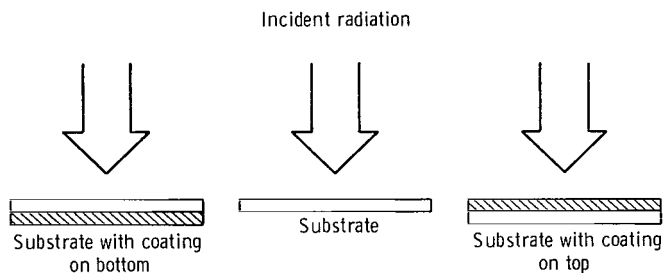


Figure 1. - Experimental sample arrangement.

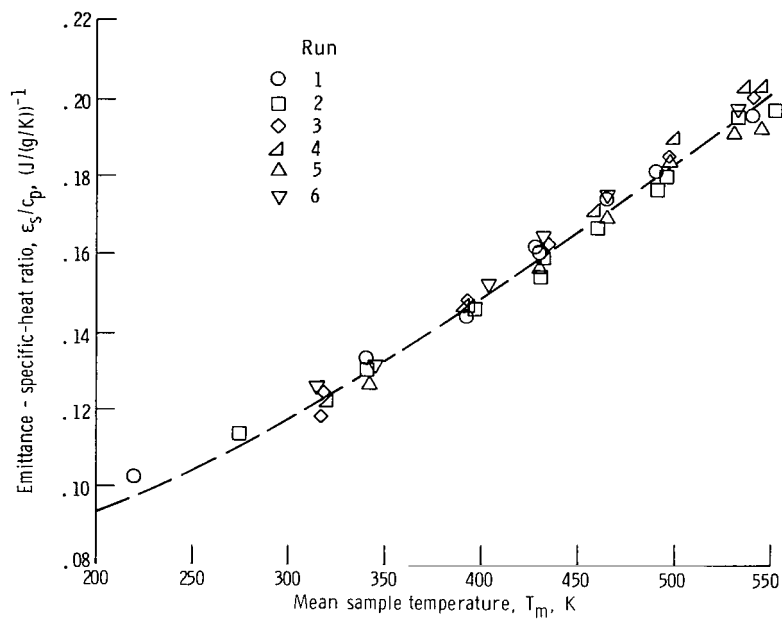


Figure 2. - Measurements of emittance - specific-heat ratio for molybdenum substrate.

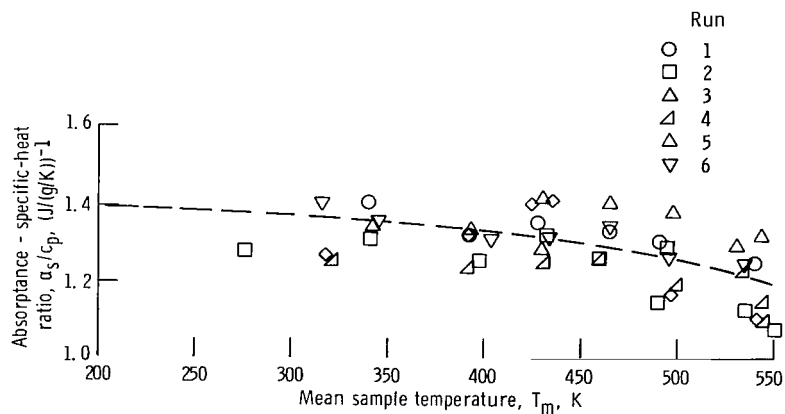


Figure 3. - Measurements of absorbance - specific heat ratio for molybdenum substrate.

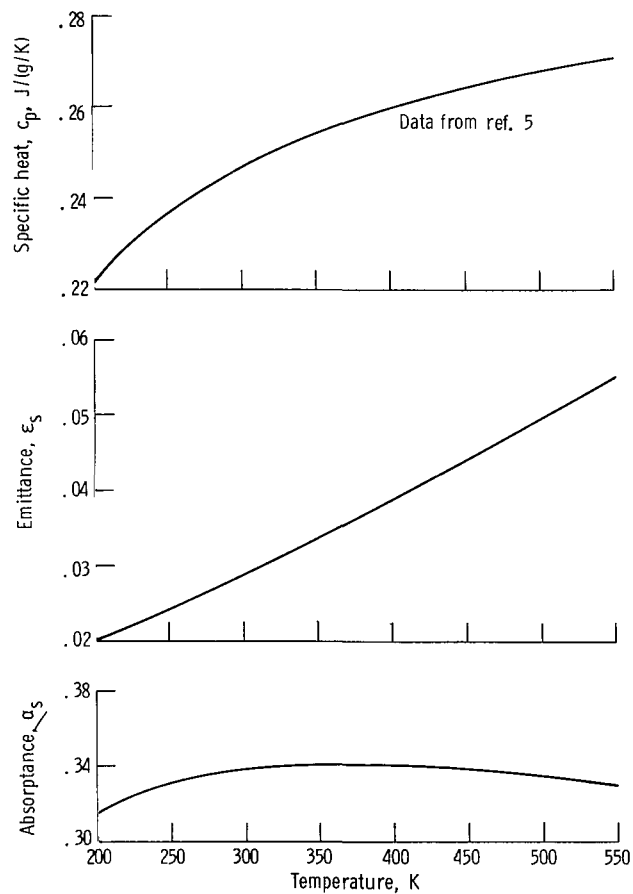


Figure 4. - Properties of molybdenum reference sample.

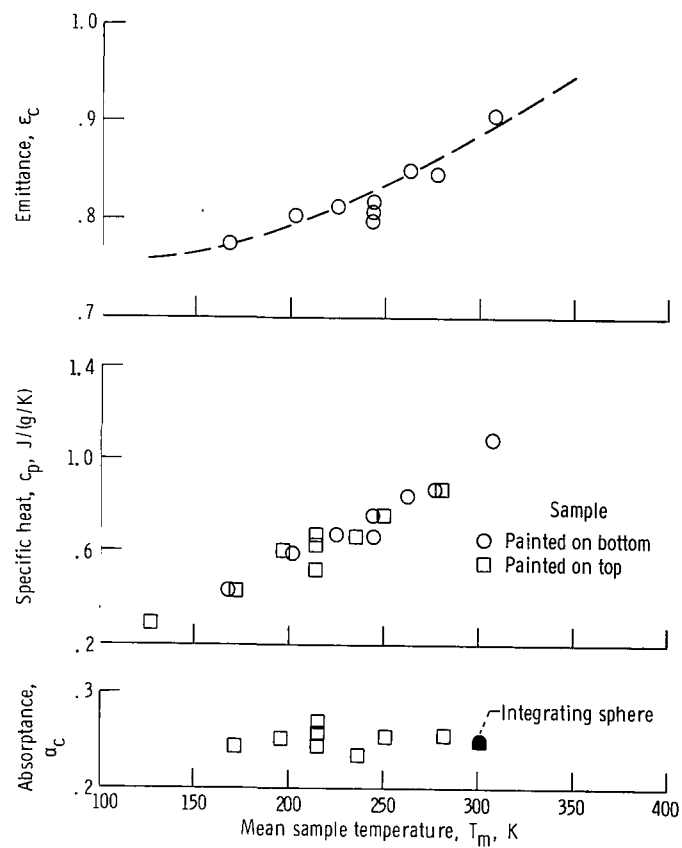


Figure 5. - Experimental data for 3M white coating.

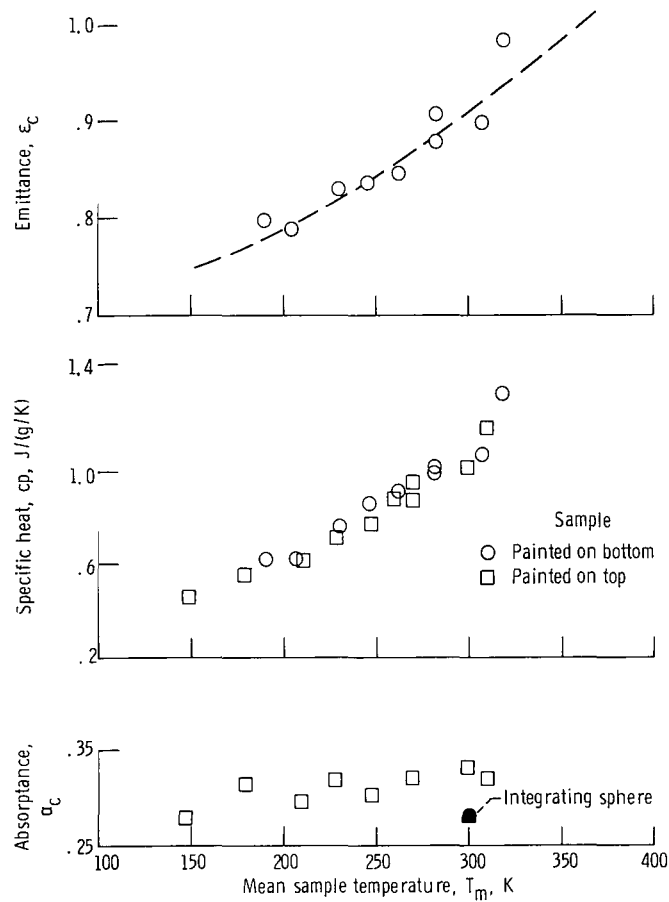


Figure 6. - Experimental data for Cat-a-lac white coating.

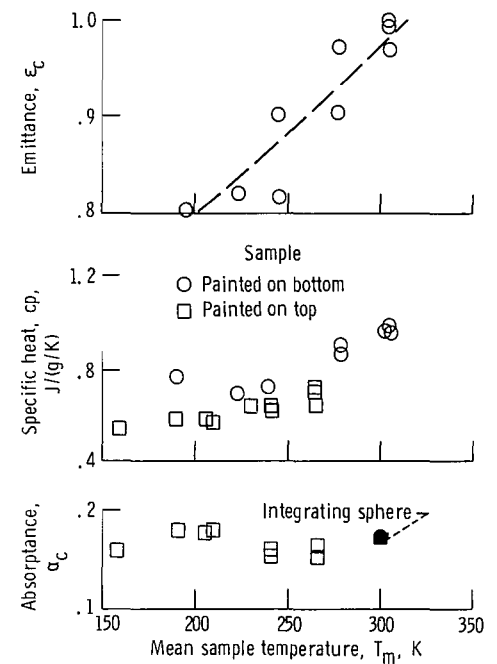


Figure 7. - Experimental data for S-13G white coating.

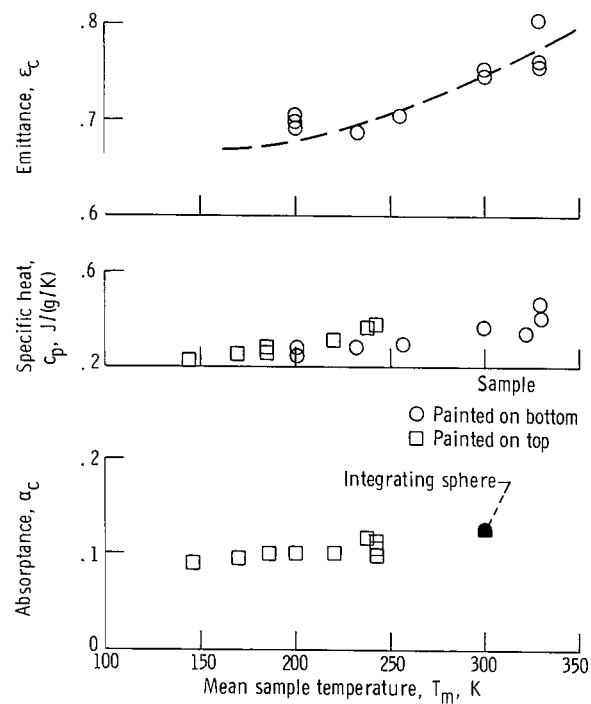


Figure 8. - Experimental data for Z-93 white coating.

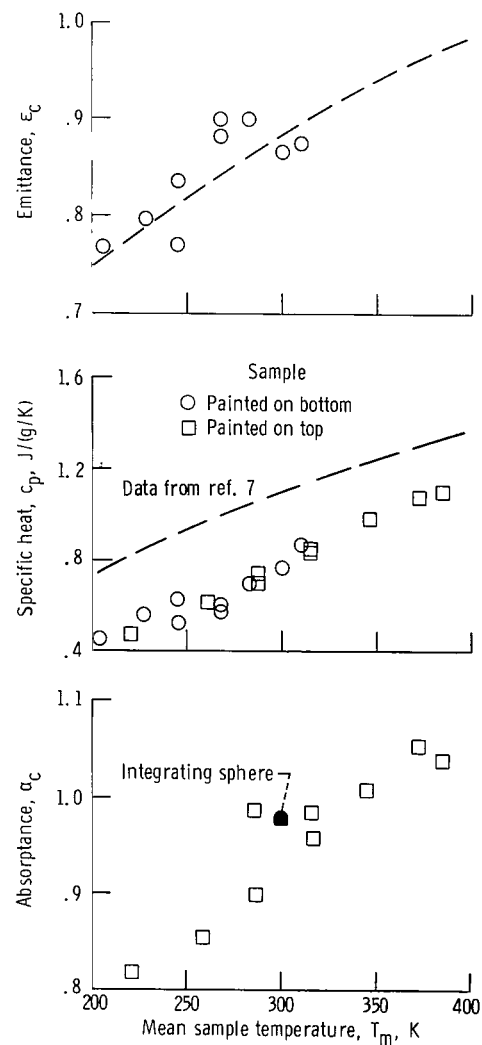


Figure 9. - Experimental data for 3M black coating.

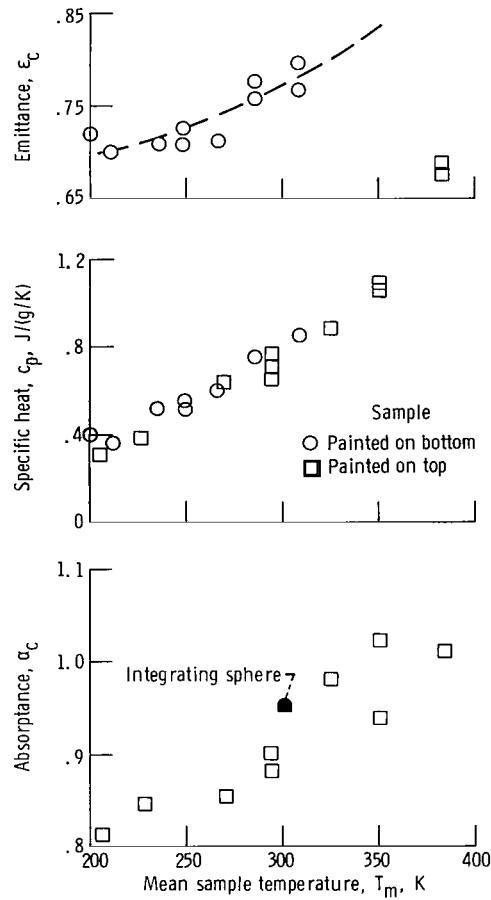


Figure 10. - Experimental data for Cat-a-lac black coating.

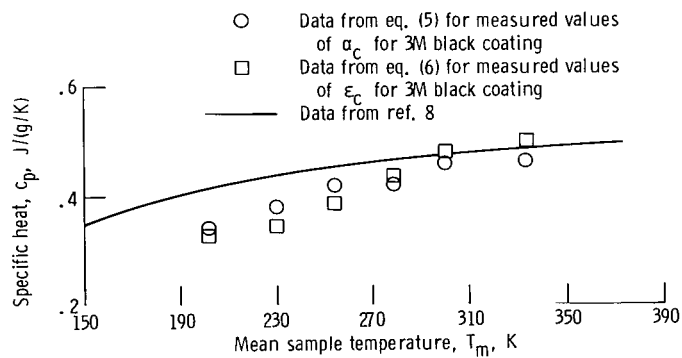


Figure 11. - Experimental specific-heat data for stainless steel 302 using 3M black paint as reference.

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